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Pre-combined GNSS-SLR solutions: What could be the benefit for the ITRF?

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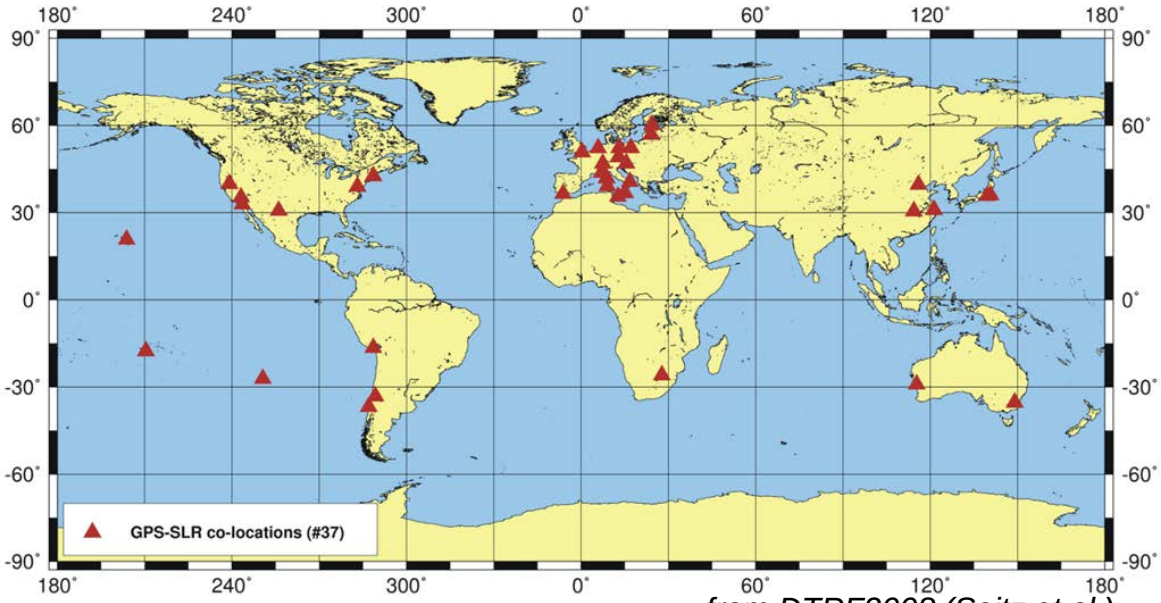
Current ITRF approach

Station co-locations are the major connection between GNSS and SLR



from DTRF2008 (Seitz et al.)

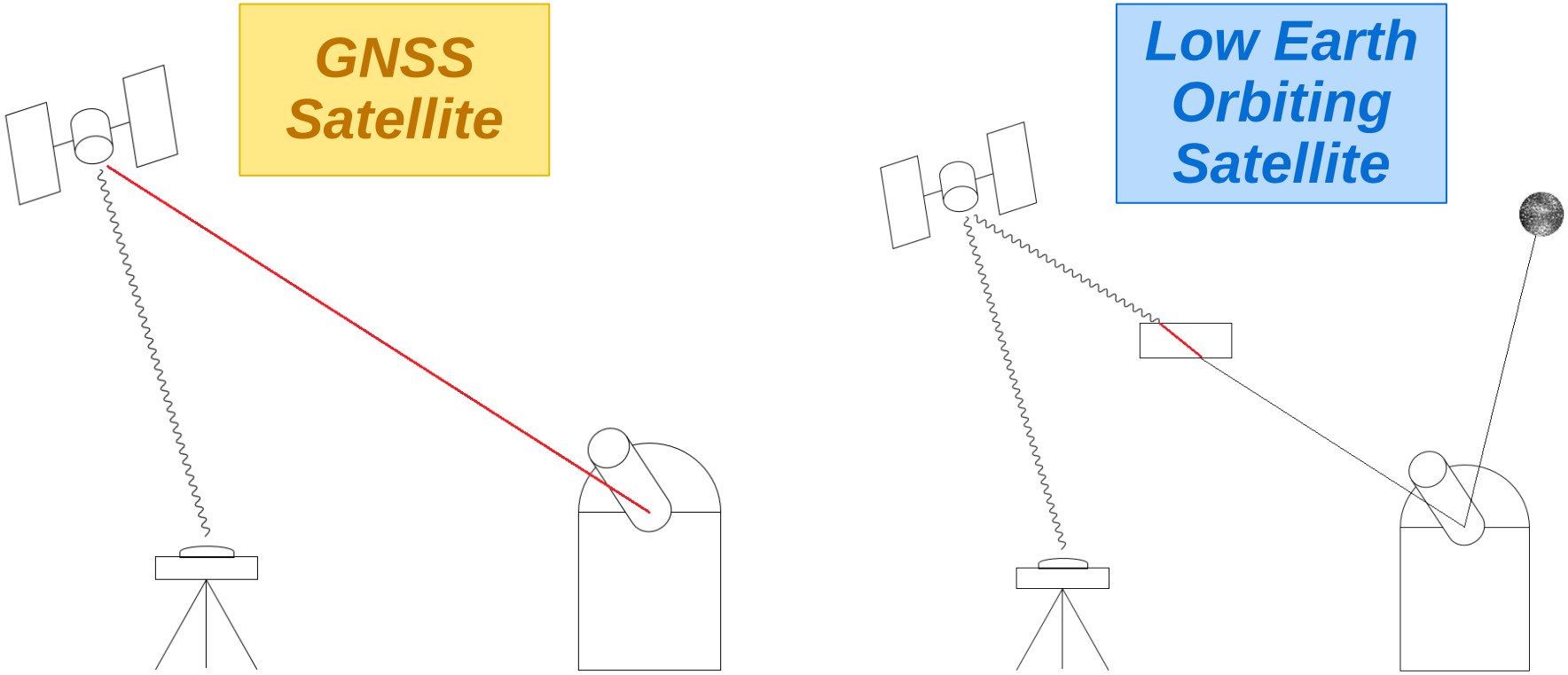
BUT:

- Only 37 co-locations
- Bad global distribution
- Issues with local ties

SLR observations to **other than LAGEOS/Etalon satellites** are ignored

Satellite co-locations
GNSS-SLR

Possible satellite co-locations for GNSS and SLR:



Satellite co-locations GNSS-SLR

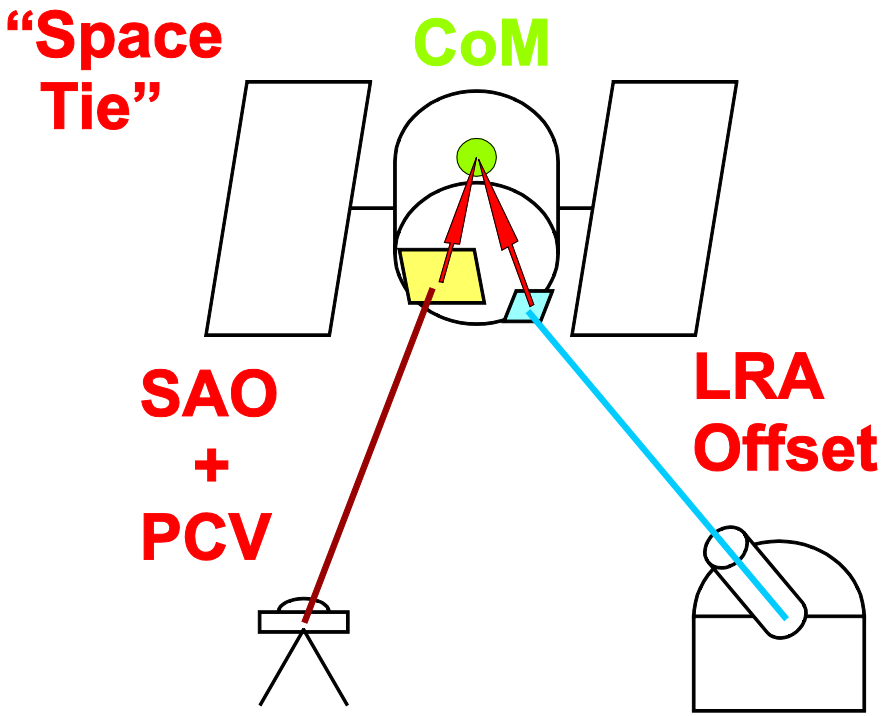
Co-location at GNSS satellites

=

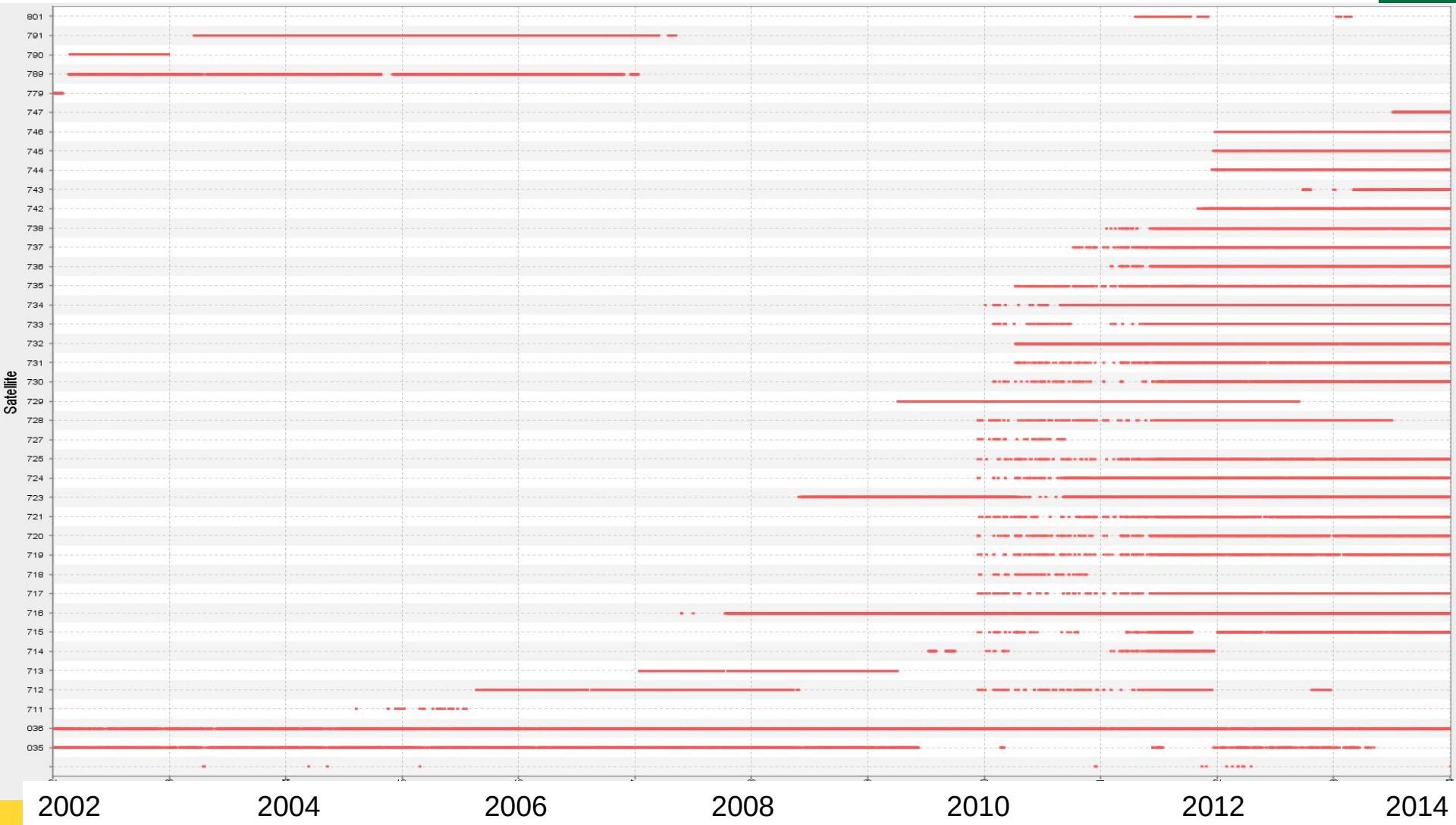
Common orbit parameters from GNSS microwave and SLR range data

→ **Vectors** of GNSS and SLR reference points **w.r.t. satellite CoM** needed:

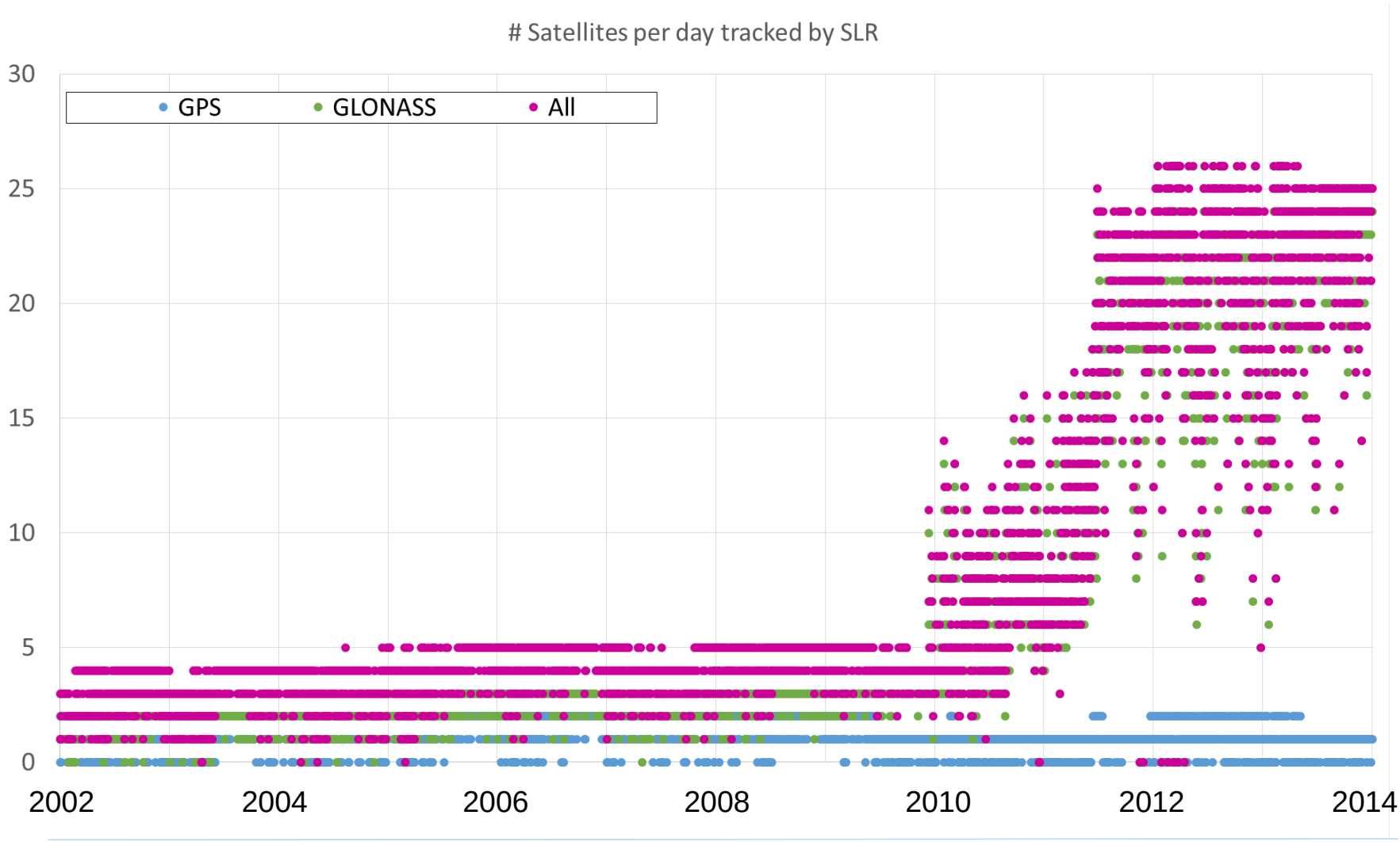
- Satellite Antenna Offsets (SAO)
- Offset of Laser Retro-reflector Array (LRA)



GNSS satellite co-locations



GNSS satellite co-locations



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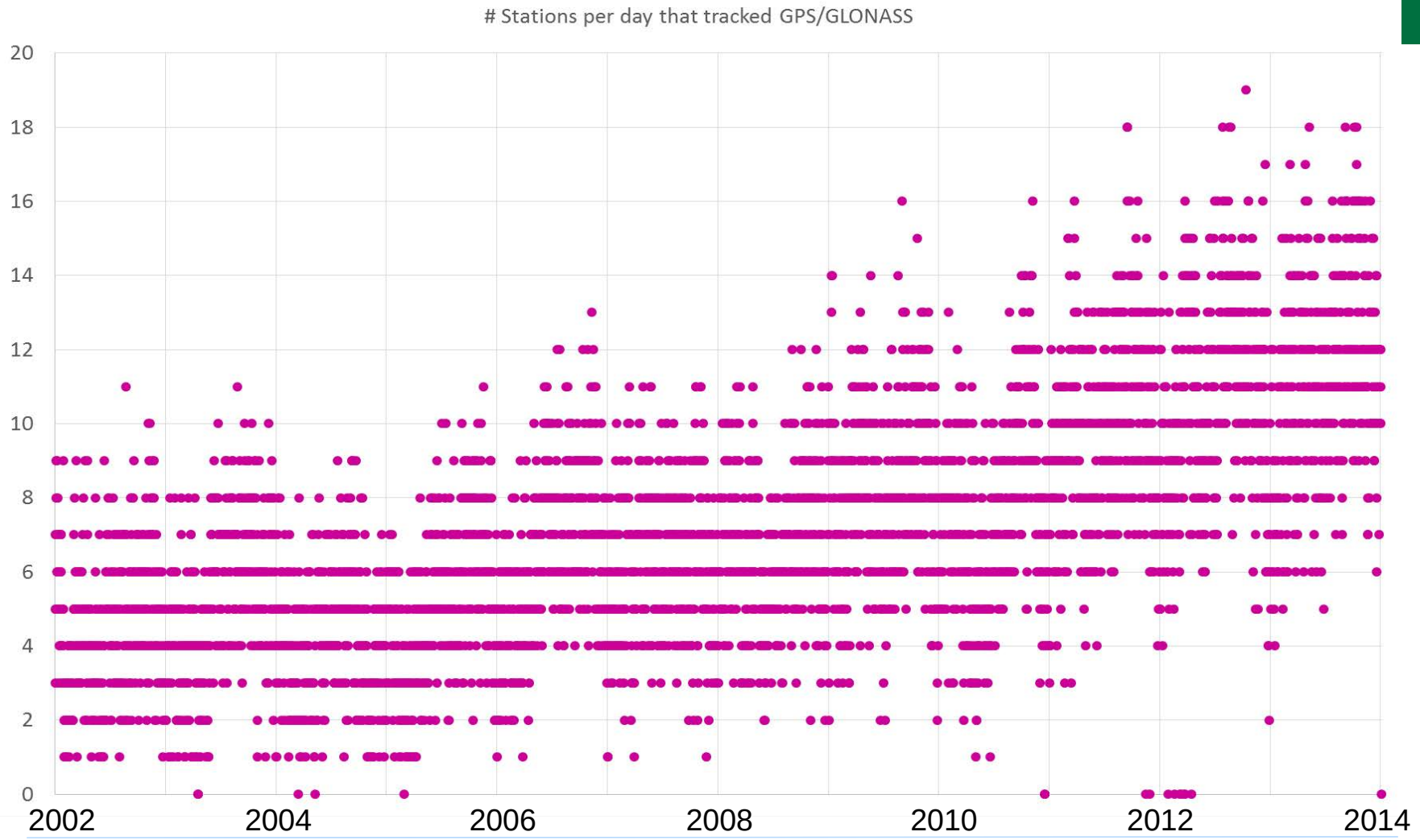
GNSS satellite co-locations



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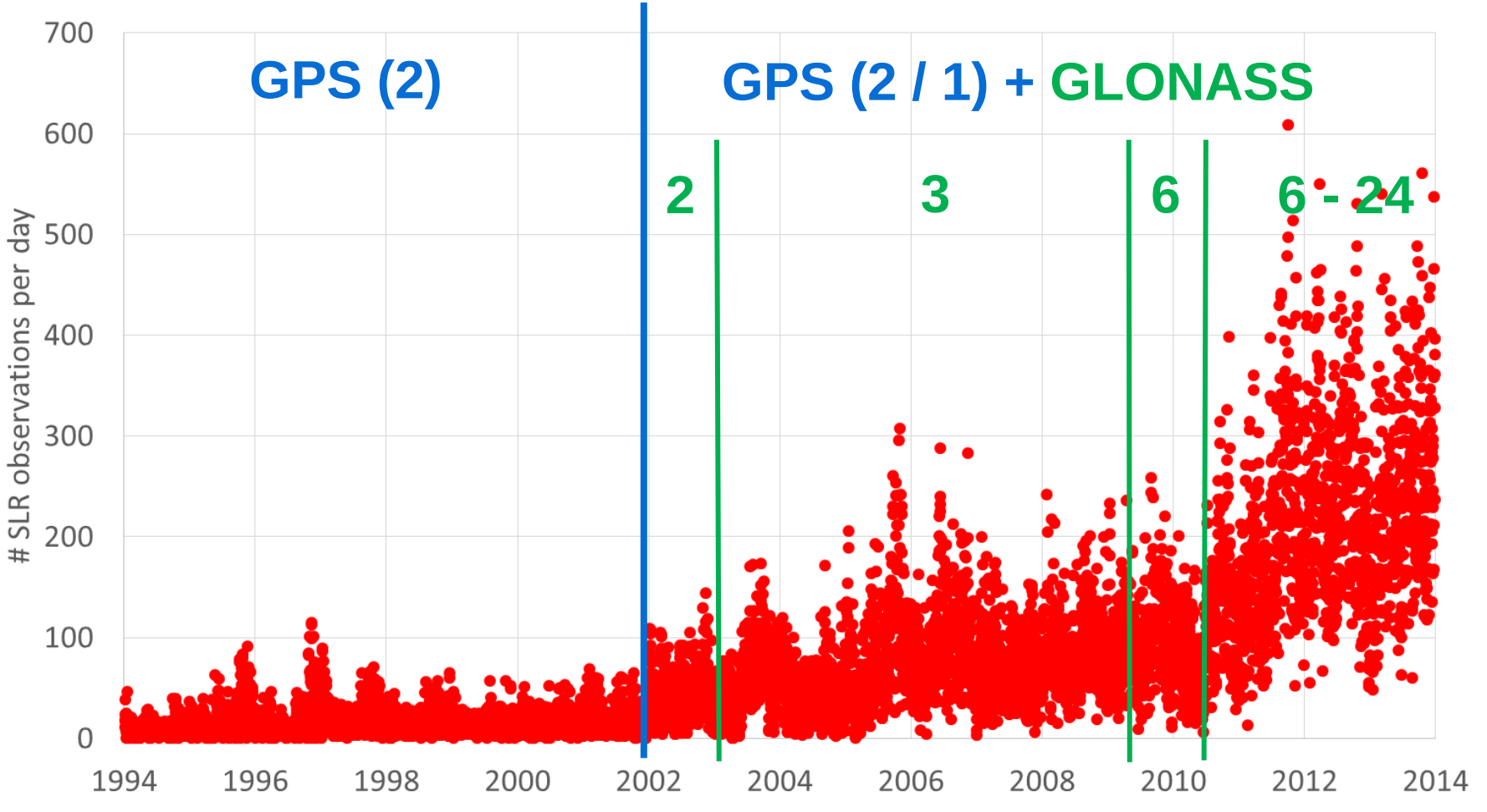
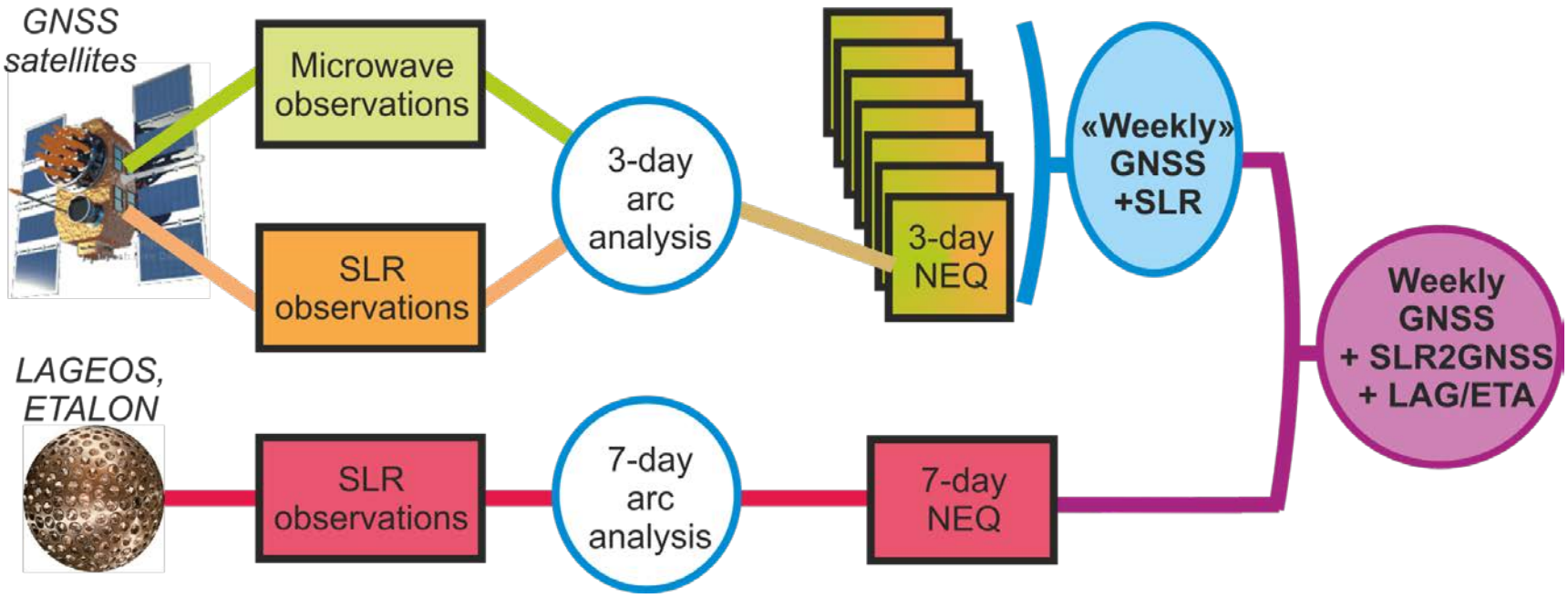
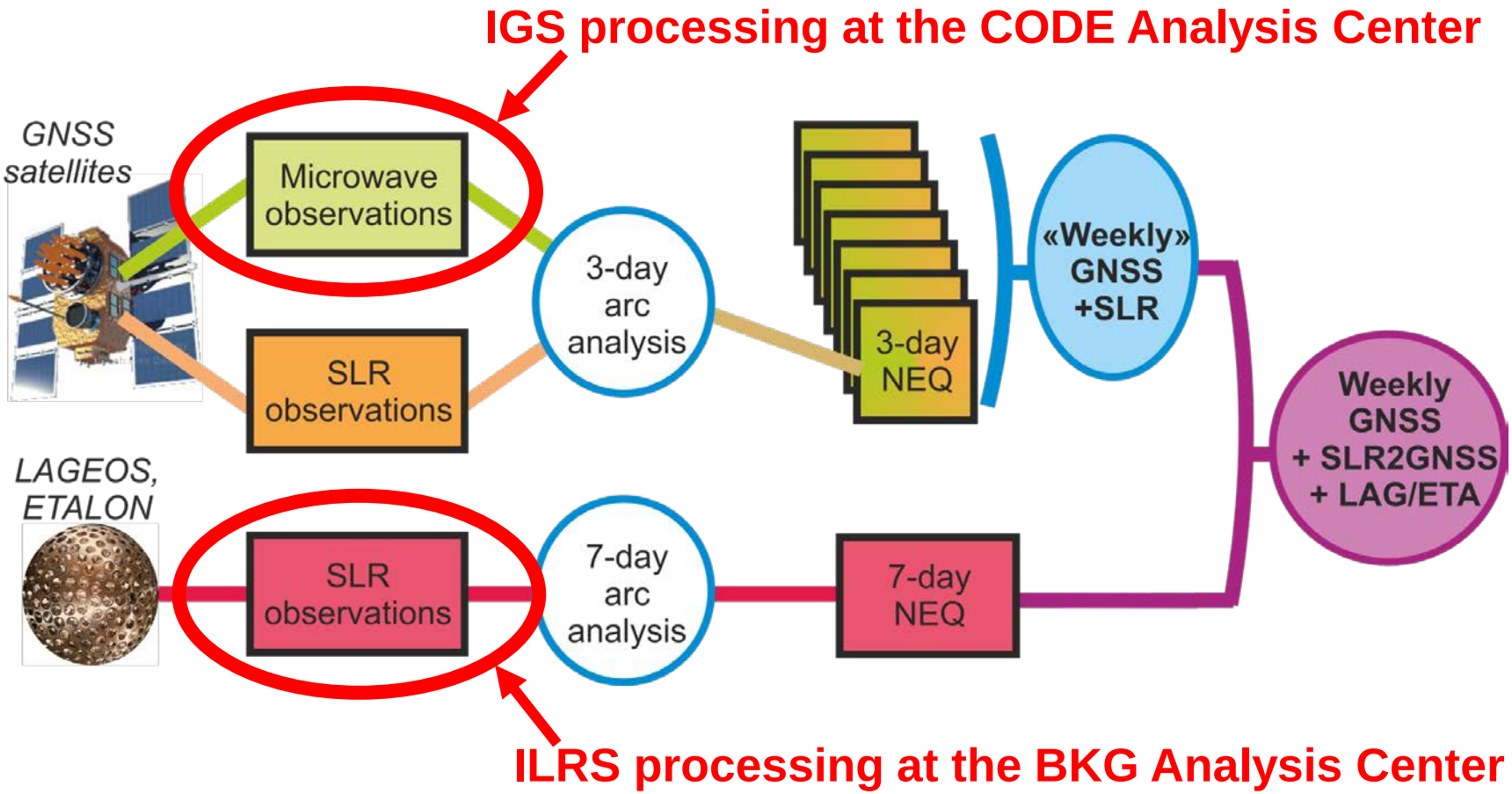
GNSS satellite co-locations



Pre-combined GNSS-SLR solutions from CODE



Pre-combined GNSS-SLR solutions from CODE



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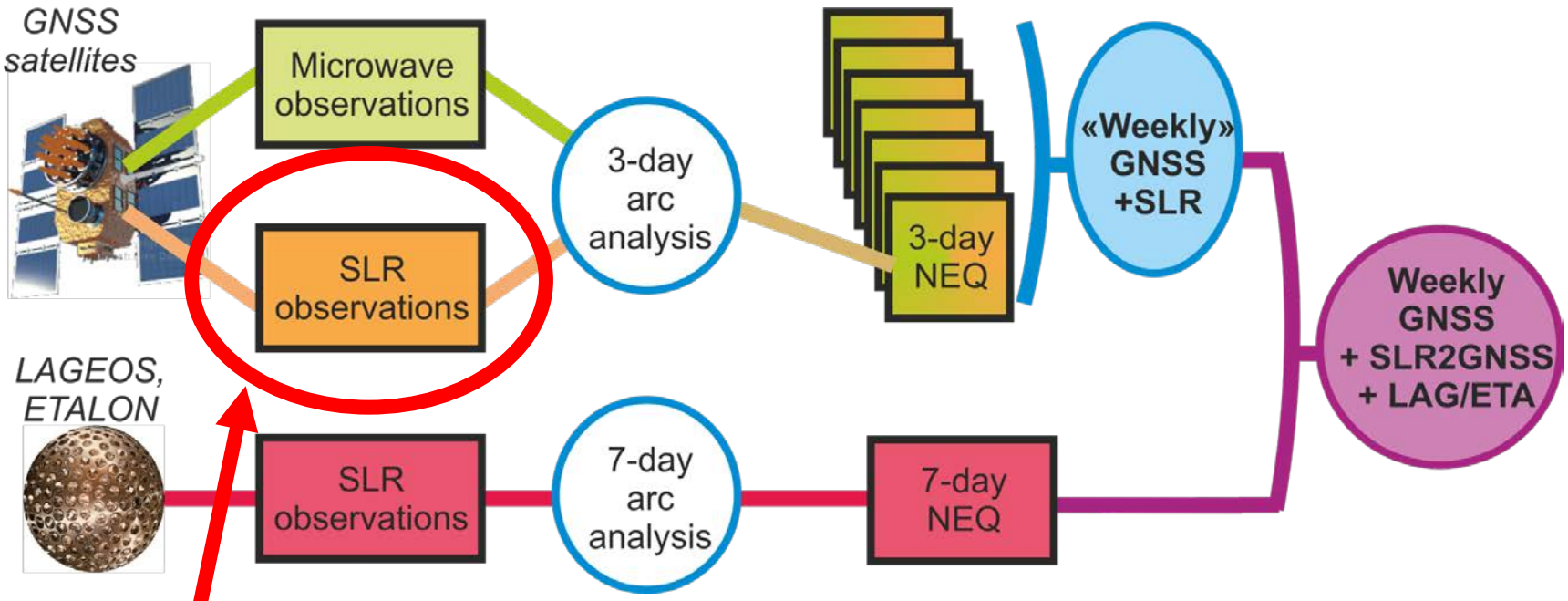


Using **co-locations at GNSS satellites** for connecting both techniques

Common parameters

Direct combination

(Indirect combination by applying **correction terms)**

	GNSS microwave	SLR @ GNSS	SLR spherical satellites
Station coordinates	GNSS	SLR	SLR
ERP	X	X	X
Geocenter	X	X	X
Orbits GNSS satellites	X	X	
Microwave Sat. antenna offsets	X		
Laser Reflector Array offsets		X	
Range Biases		X	(X)
Orbits spherical satellites			X

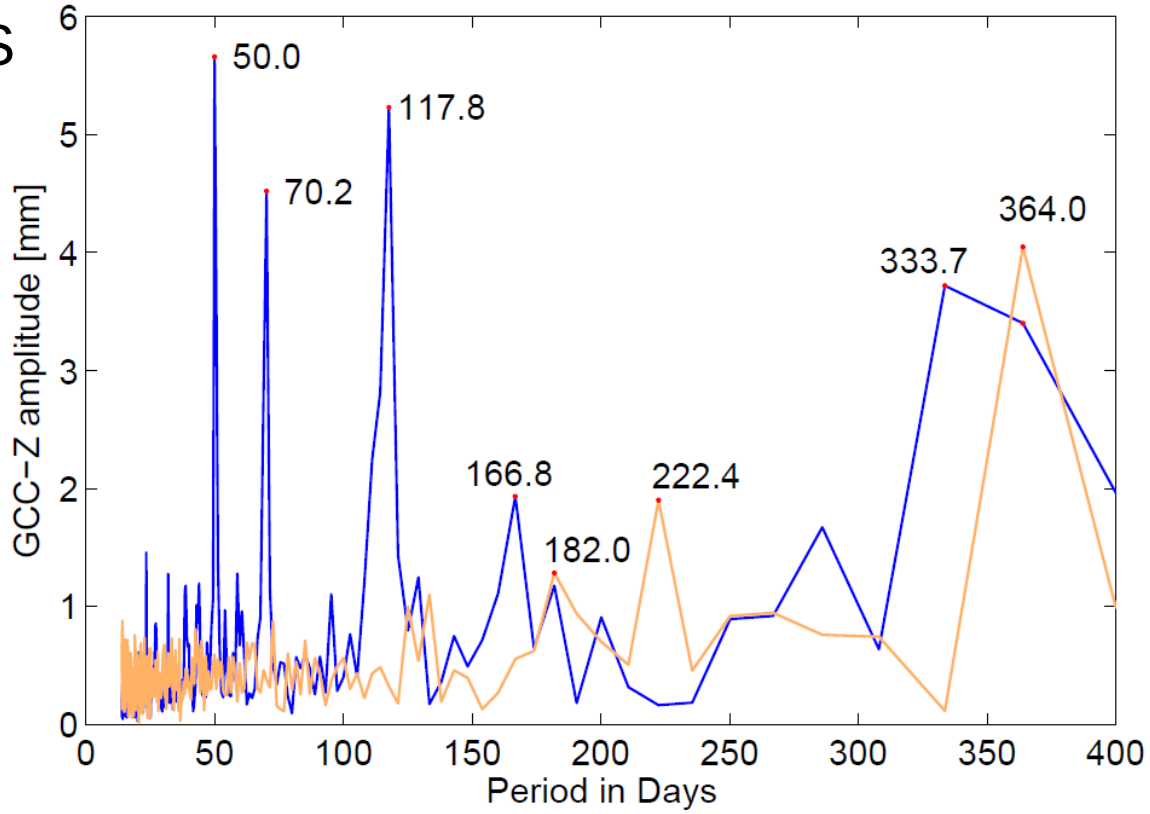
Geocenter: Single techniques

Draconitic year is visible: GNSS = 352d, LAG-2 = 222d

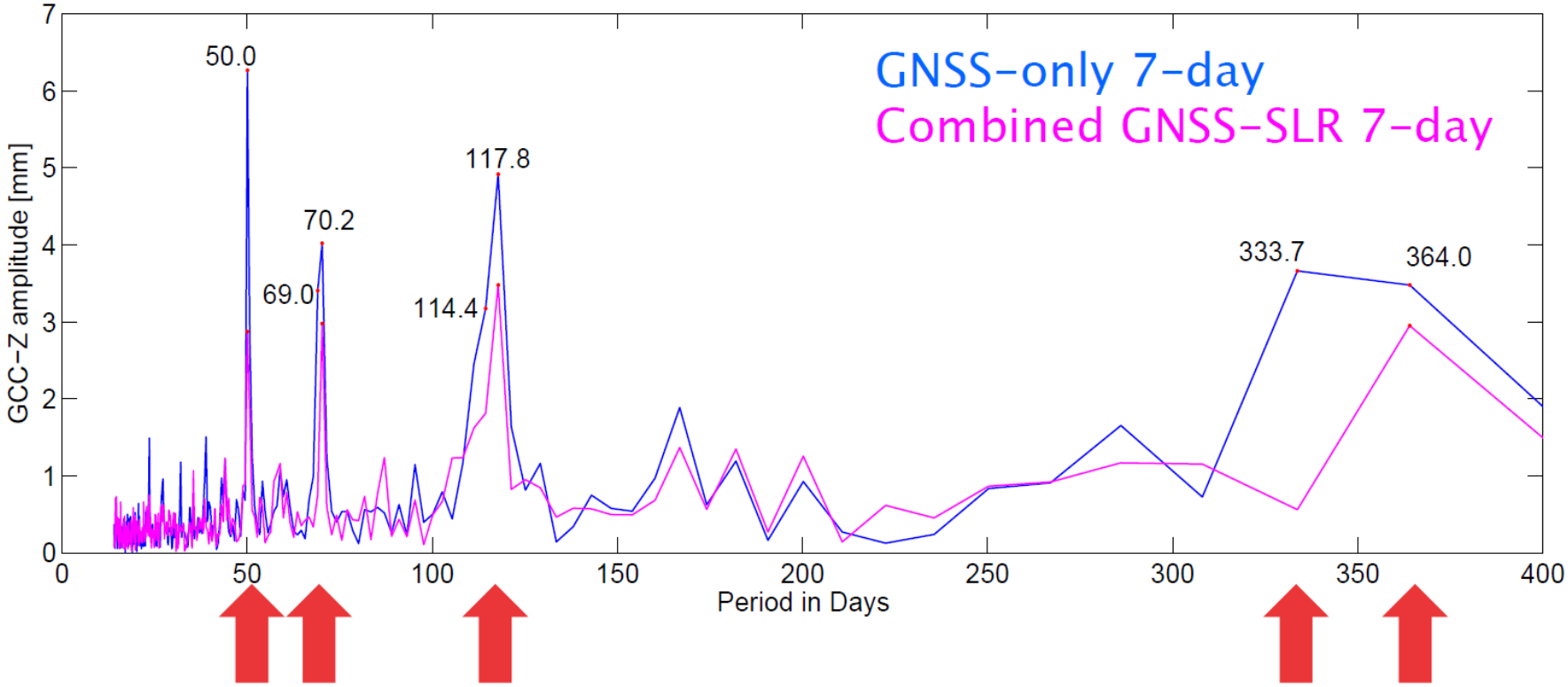
+ Harmonics for GNSS

GNSS-only

SLR-only

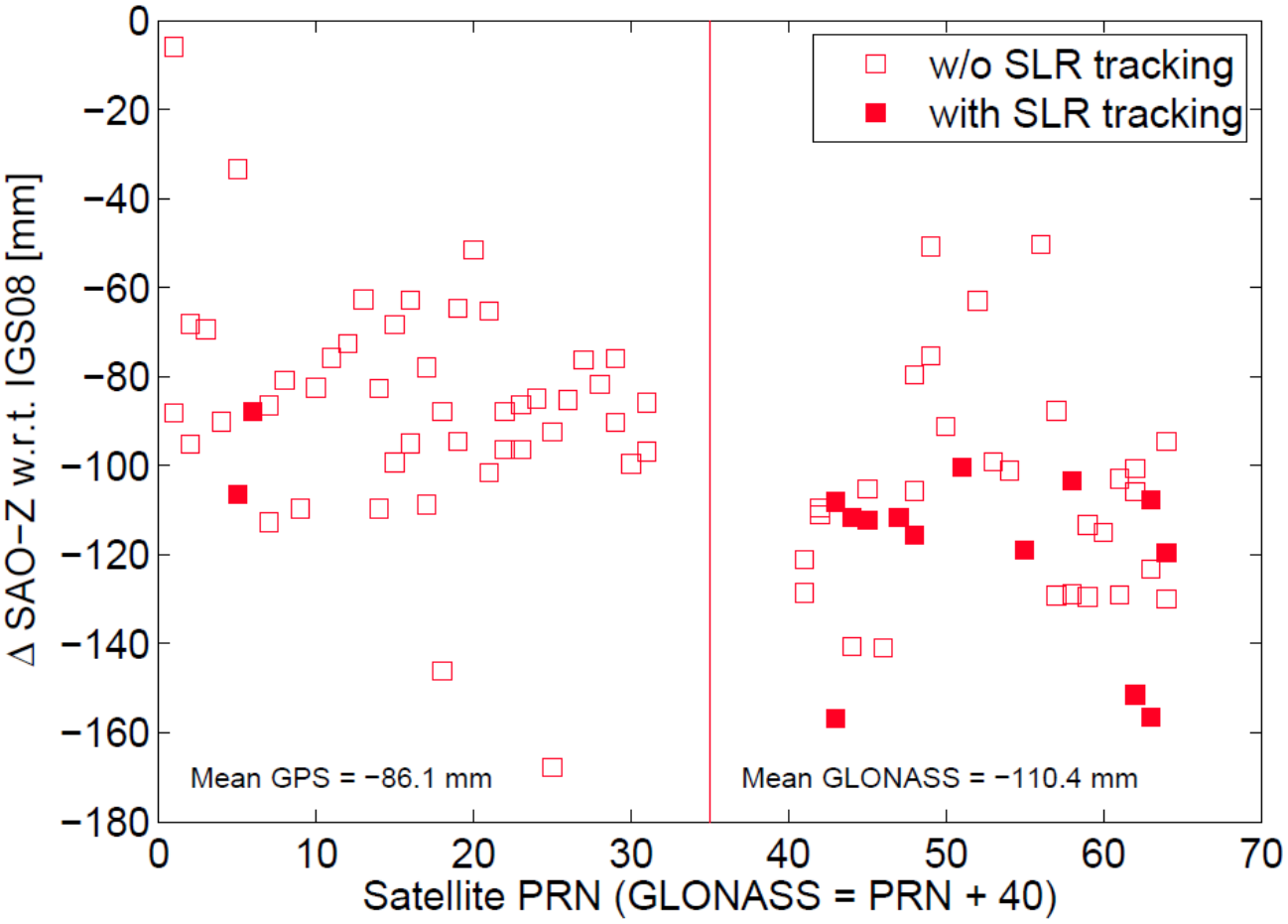


Geocenter: Combined solutions



- Annual signal remains; draconitic signals disappear
- Harmonics of draconitic GNSS year are reduced, but not eliminated

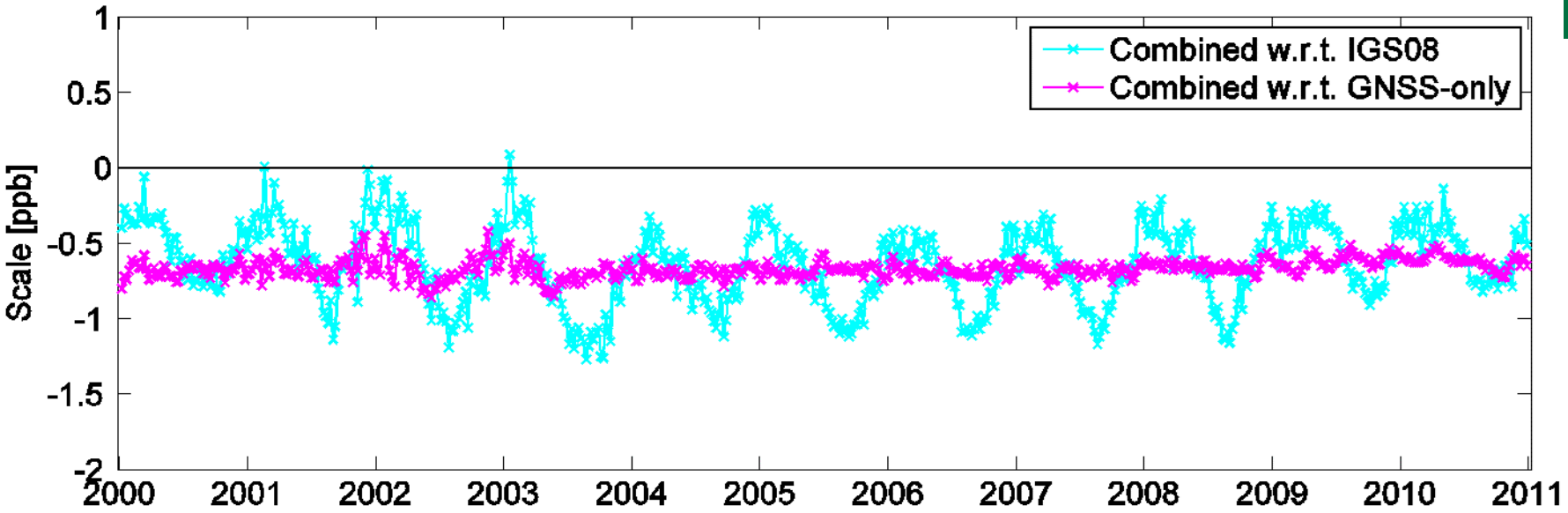
Satellite antenna offsets



Mean GPS =
-86.1 mm

Mean GLONASS =
-110.4 mm

Scale



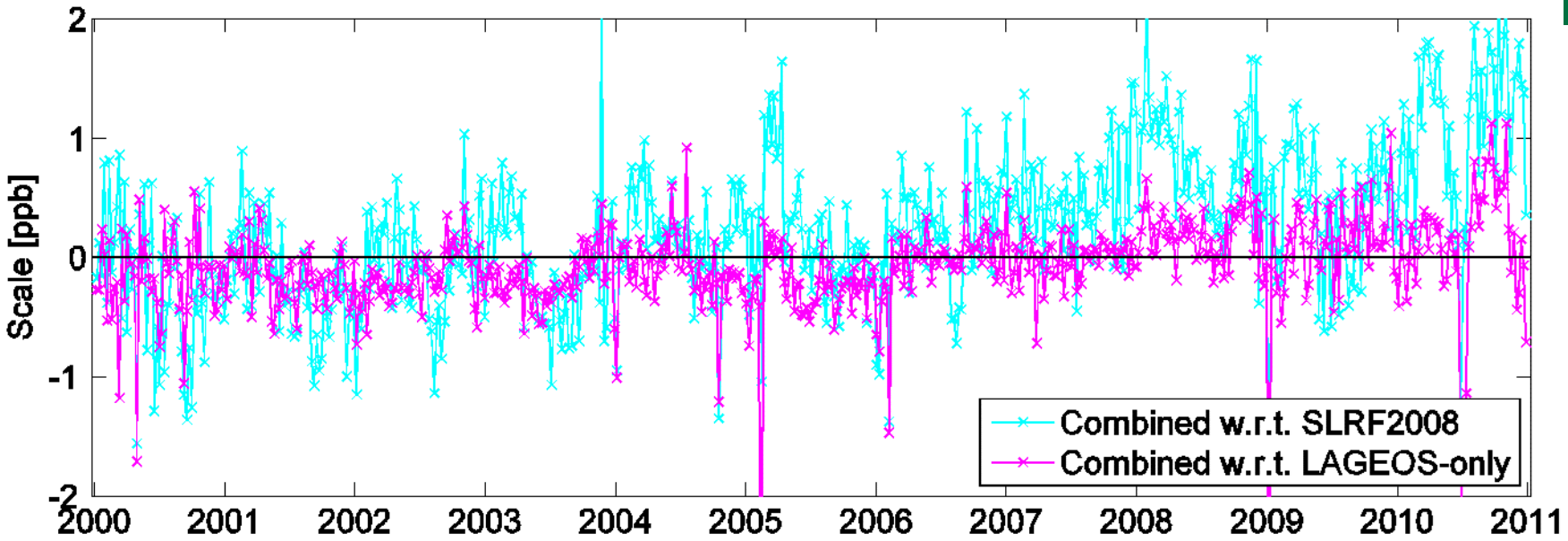
SAO-Z is correlated with scale: $\Delta Scale\ [ppb] = -7.8 \cdot \Delta SAOz\ [m]$

$\Delta SAOz\ (GPS) = -86.1\ mm \quad \Rightarrow \Delta scale = 0.67\ ppb$

$\Delta SAOz\ (GLONASS) = -110.4\ mm \quad \Rightarrow \Delta scale = 0.86\ ppb$

SAO corrections are absorbed by the GNSS network scale

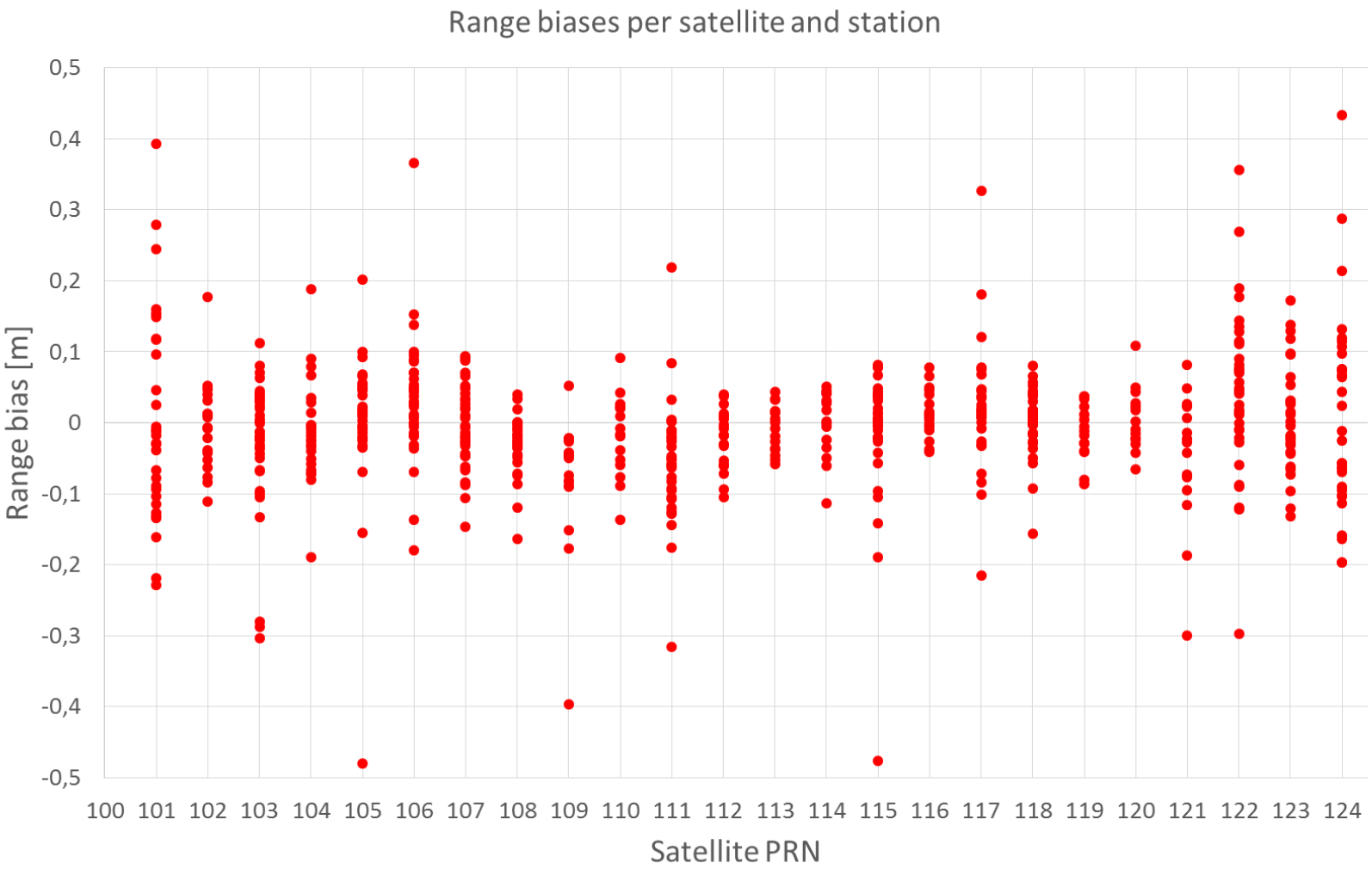
Scale



- No systematic scale difference for the SLR network
- Scale from SLR is transferred to the combined solution

SAO corrections are fully consistent to the SLR scale

Range biases

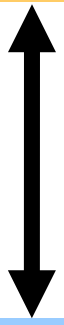


Local ties: Validation

„Local Tie“:

3D vector between reference points of space geodetic instruments (GNSS antenna or SLR telescope or …) at co-located sites

From terrestrial measurements



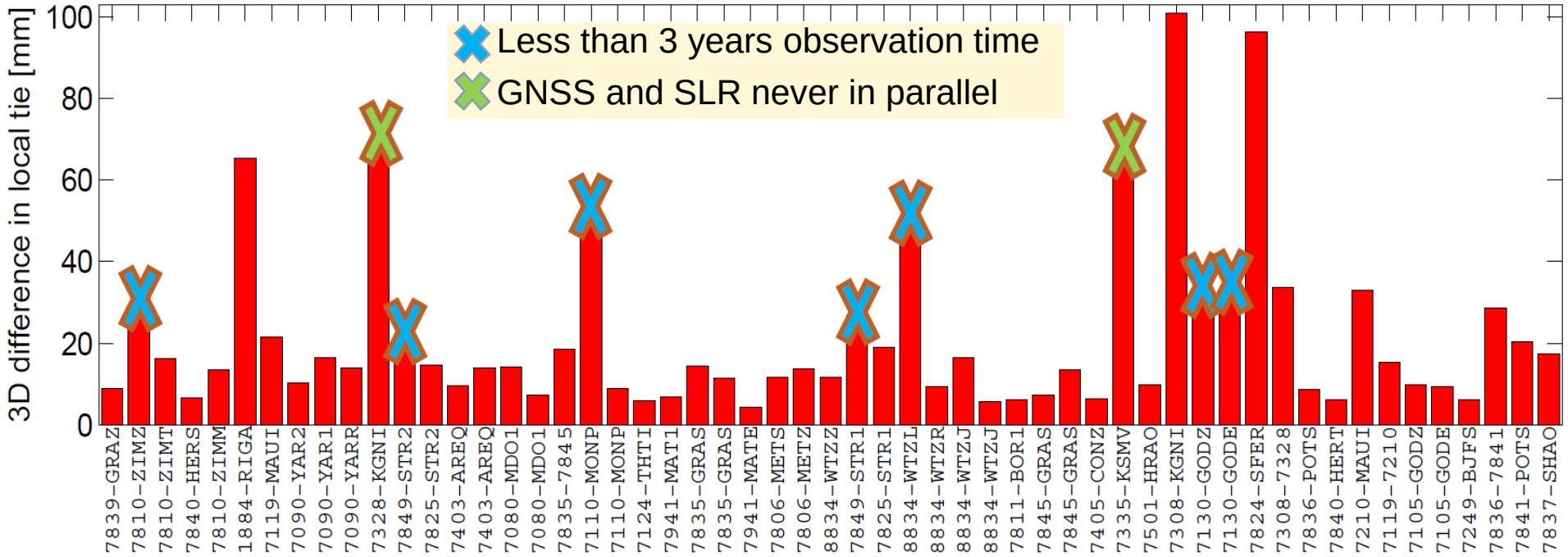
Discrepancies have to be evaluated

Station coordinates from space techniques:

3D position of reference points of space geodetic instruments

From combined GNSS-SLR solutions using satellite co-locations,
without using Local Ties !!!

Local ties: 3D discrepancies



3-D agreement:

$0 \text{ mm} < \Delta \leq 10 \text{ mm}$	17 co-locations
$10 \text{ mm} < \Delta \leq 20 \text{ mm}$	13 co-locations
$20 \text{ mm} < \Delta \leq 30 \text{ mm}$	5 co-locations
$30 \text{ mm} < \Delta$	15 co-locations

Summary (1)

- Satellite co-locations provide an additional connection to strengthen inter-technique combination
- Independent validation of station co-locations:
  - Local ties from terrestrial measurements
  - Coordinate differences from space-geodetic techniques
- Benefit for scale, geocenter
- More data from space-geodetic stations are included in reference frame computation

Summary (2): „To Do“

- For our contribution to ITRF2013:
  - Generate best-possible multi-year solution
  - Verify Range Biases, SAO and LRA corrections
  - Generate weekly SINEX

- For ITRF-like combinations including pre-combined solutions:
  - Weighting issues (single-technique vs. pre-combined)
  - Handling of additional parameters (e.g. range biases, antenna offsets for GNSS and SLR)

Thank you for your kind attention!

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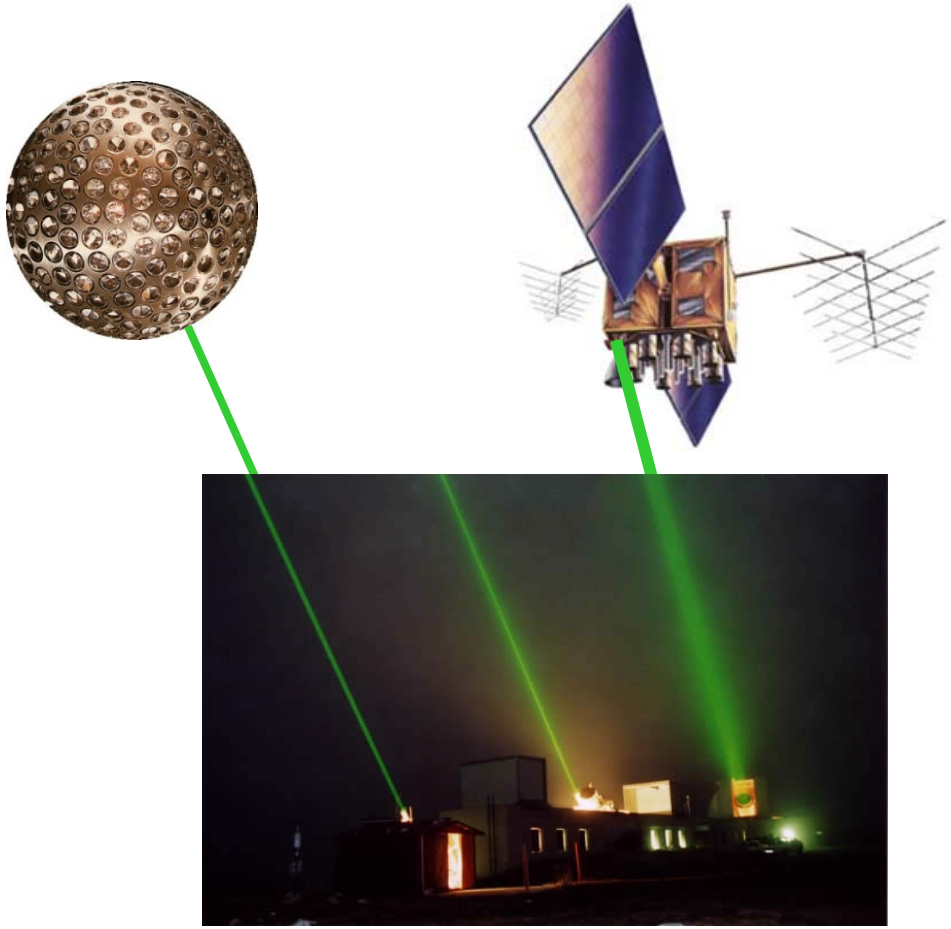
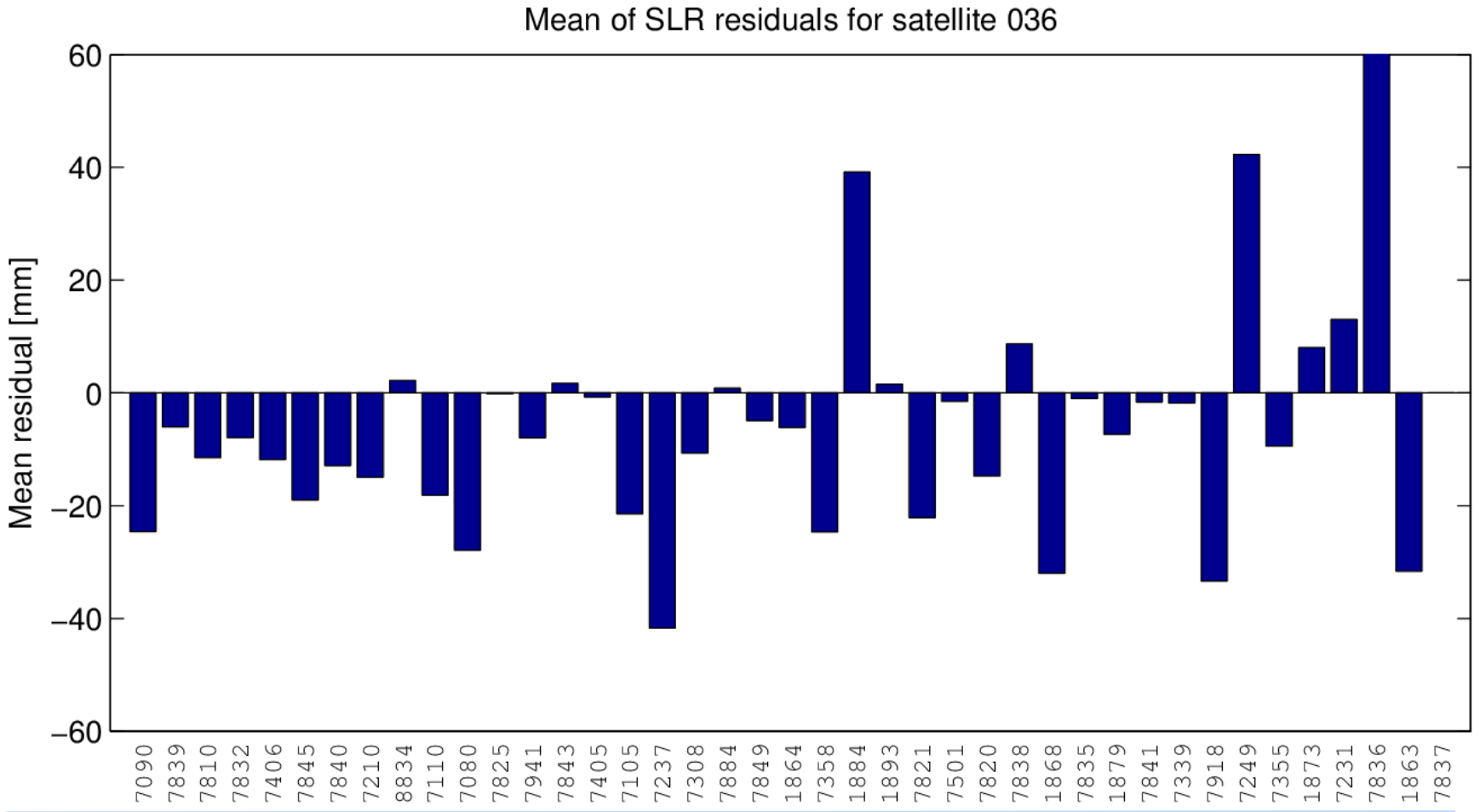
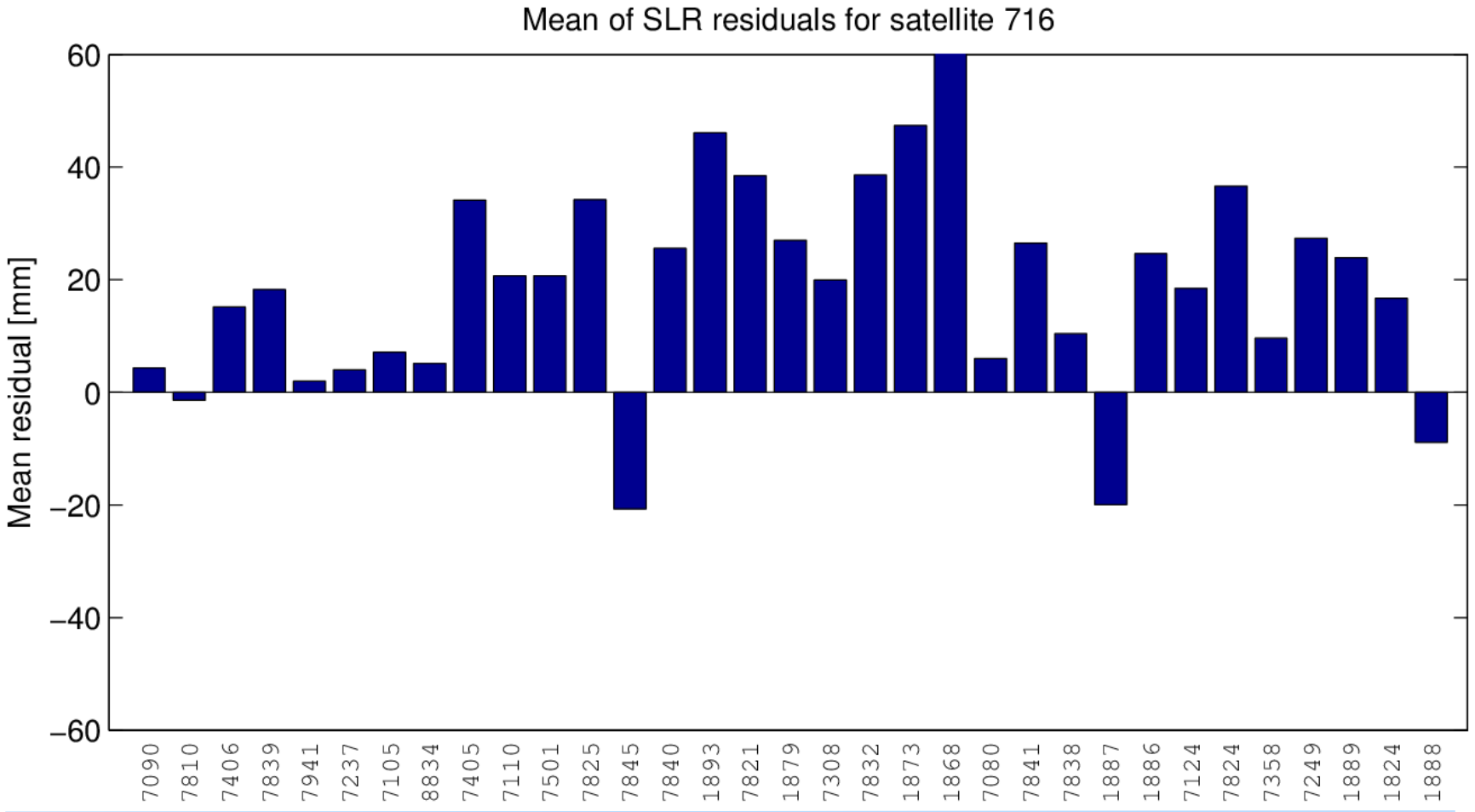


Mean of SLR residuals: G-036 for 1994 - 2014



Mean of SLR residuals: R-716 for 2007 - 2014



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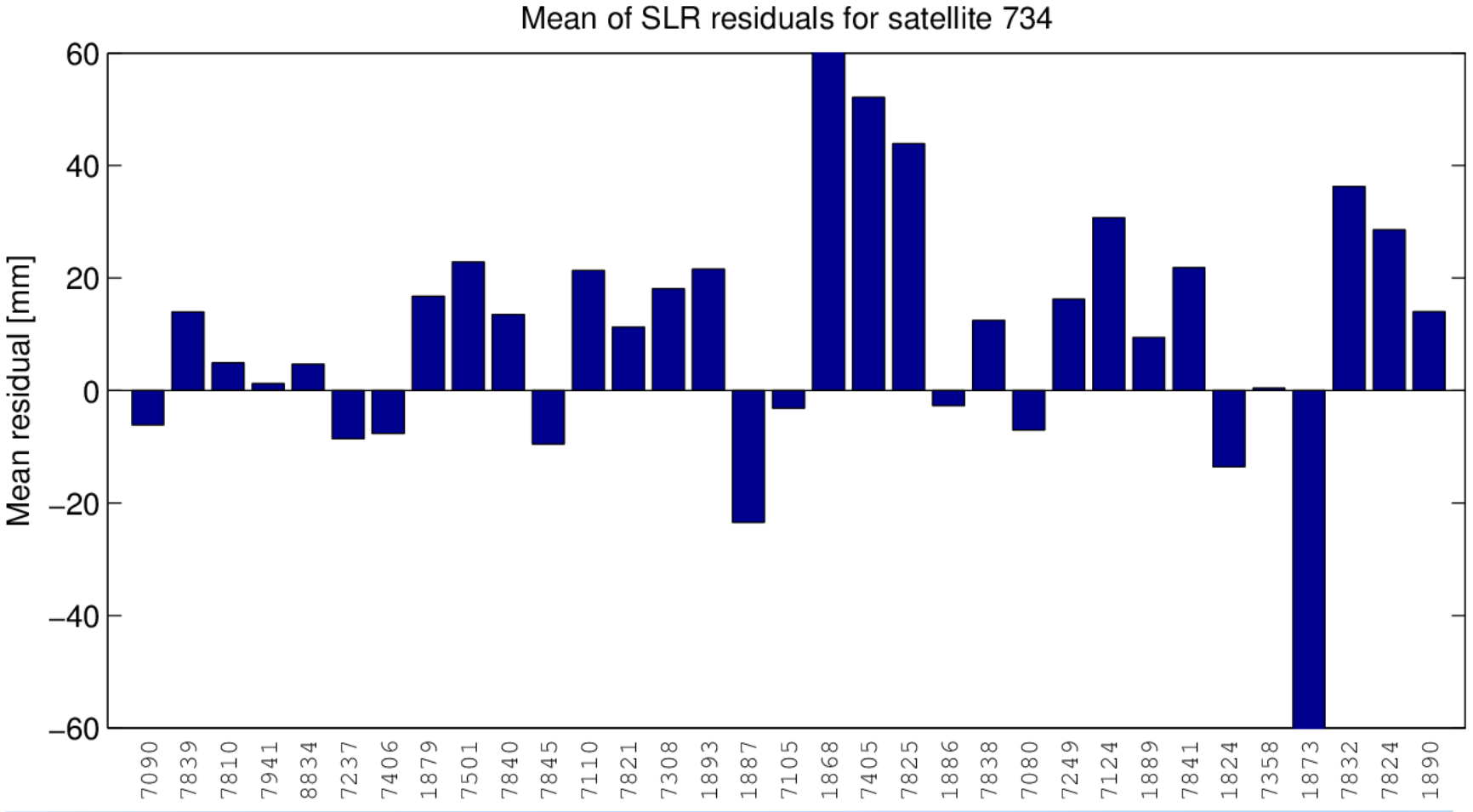
Mean of SLR residuals: R-734 for 2010 - 2014



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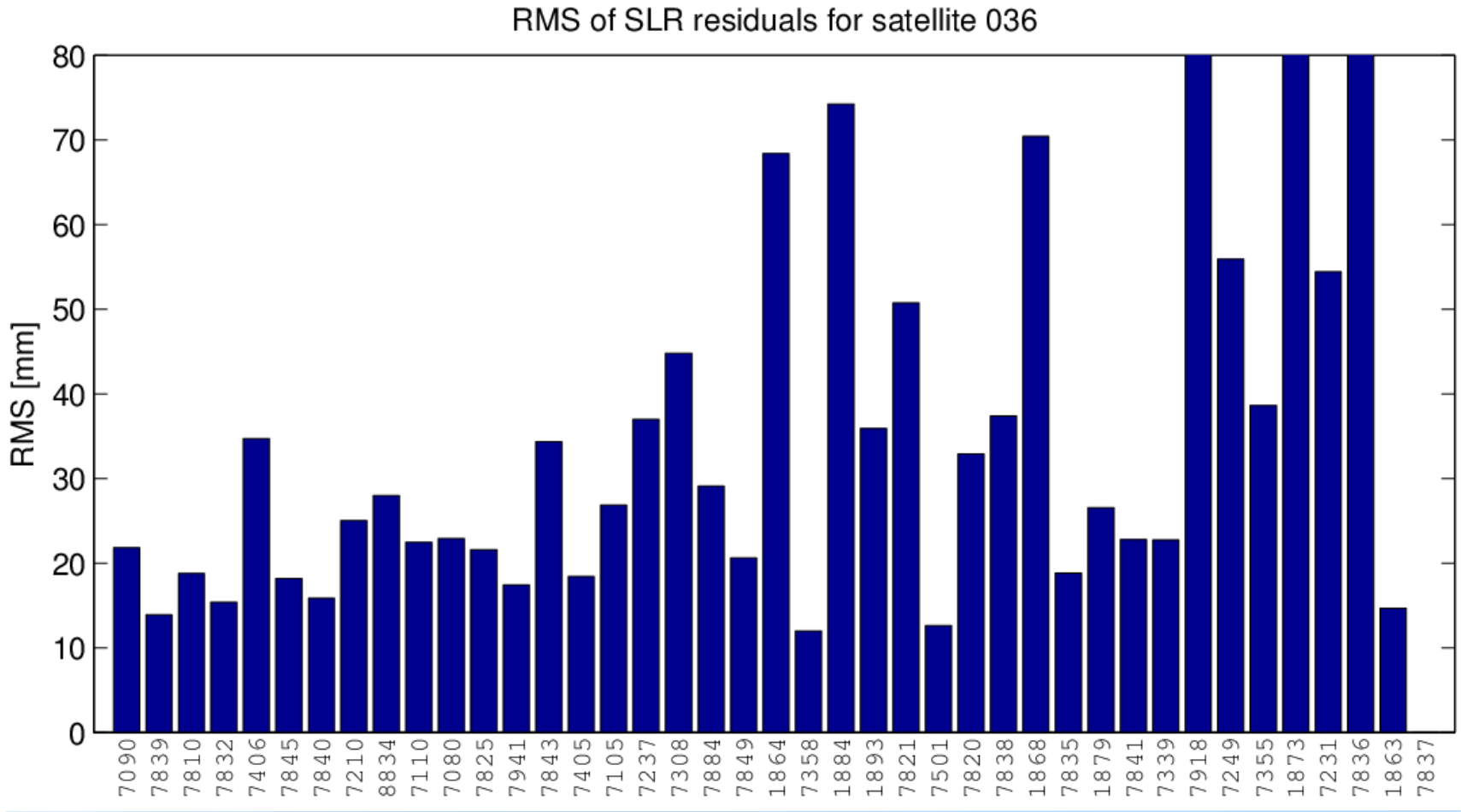
RMS of SLR residuals: G-036 for 1994 - 2014



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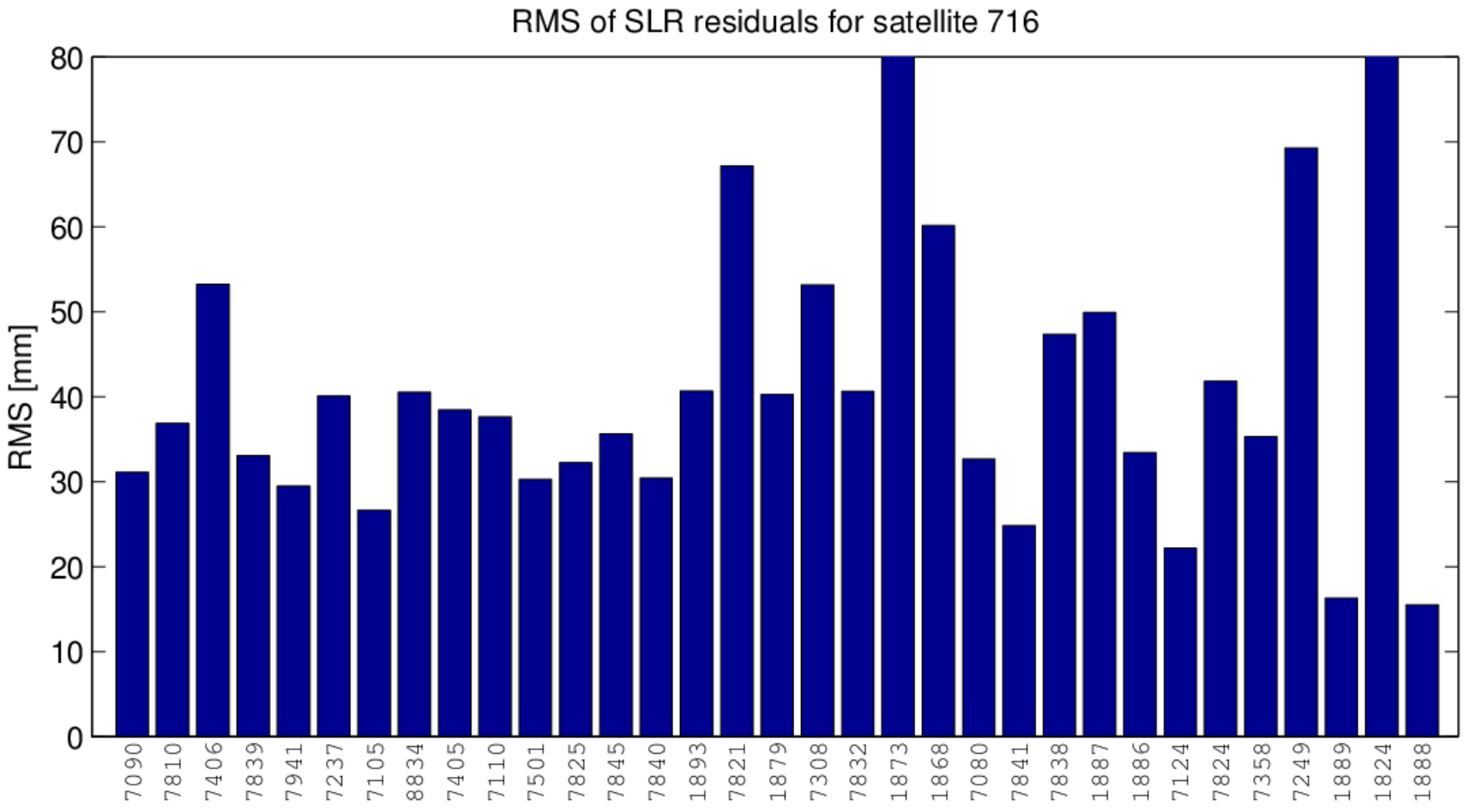
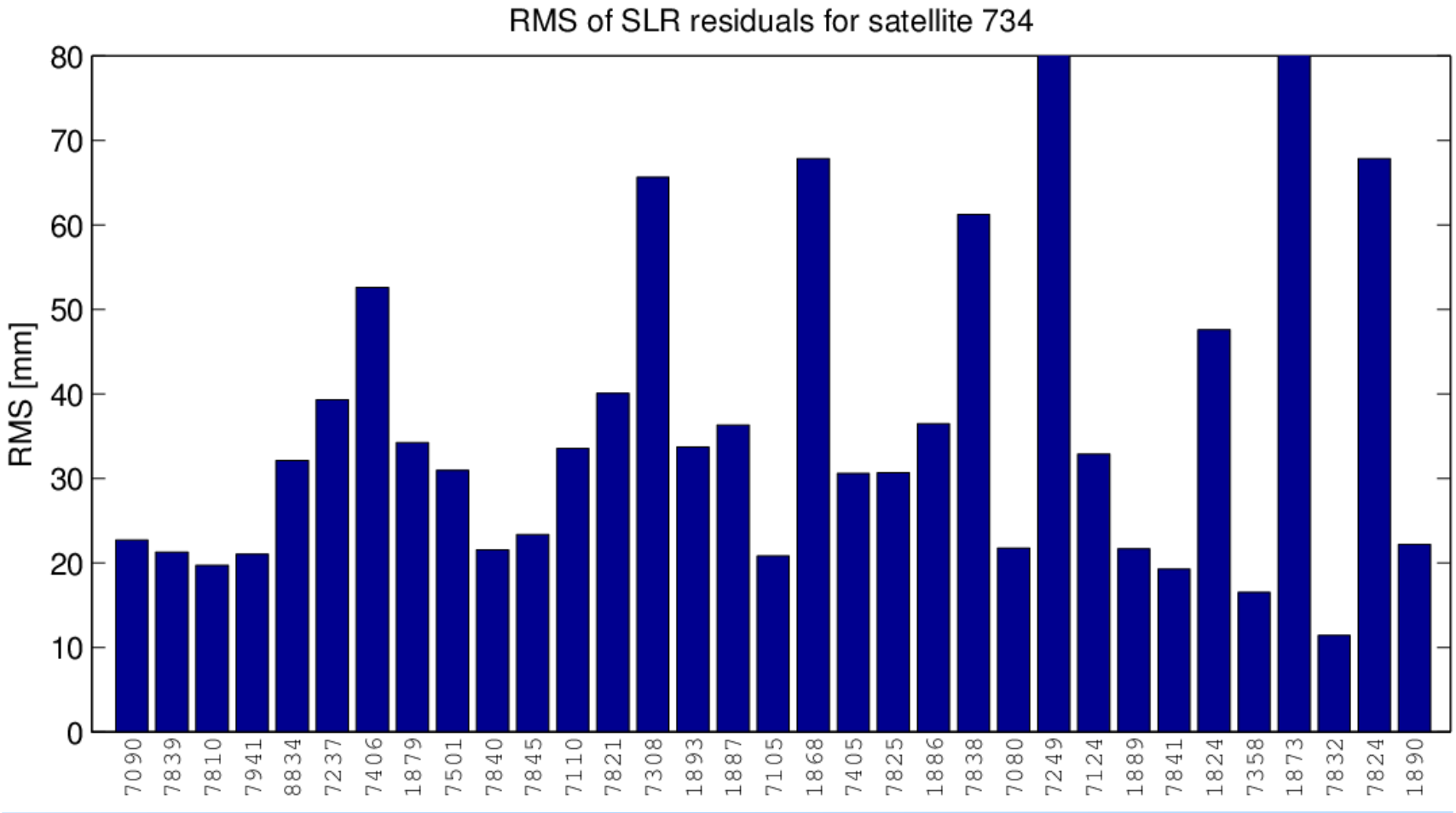
RMS of SLR residuals: R-716 for 2007 - 2014



RMS of SLR residuals: R-734 for 2010 - 2014



GNSS satellite co-locations

- Number of SLR Observations per day

```
Median nObs for year 1994:   8
Median nObs for year 1995:  16
Median nObs for year 1996:  13
Median nObs for year 1997:  19
Median nObs for year 1998:  14
Median nObs for year 1999:  12
Median nObs for year 2000:  14
Median nObs for year 2001:  16
Median nObs for year 2002:  43
Median nObs for year 2003:  48
Median nObs for year 2004:  42
Median nObs for year 2005:  74
Median nObs for year 2006:  84
Median nObs for year 2007:  70
Median nObs for year 2008:  86
Median nObs for year 2009:  93
Median nObs for year 2010:  98
Median nObs for year 2011: 177
Median nObs for year 2012: 228
Median nObs for year 2013: 230
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